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Fifth Period Progress Report

Research and Development
in
CdS Photovoltaic Film Cells

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by

T. A. Griffin,
J.C. Schaefer,
and
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26 Nov. 1963 26p

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~~The Harshaw Chemical Company~~
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Period of 26 July 1963 to 26 November 1963

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National Aeronautics and Space Administration
Technical Management
NASA-Lewis Research Center
Auxiliary Power Generation Office

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FORWARD

The work of this project has been carried out at the Crystal-Solid State Research Laboratory of the Harshaw Chemical Company at 2240 Prospect Ave., Cleveland, Ohio. Project direction has been provided by Mr. J. C. Schaefer. Mr. T. A. Griffin has acted as the Project Supervision Engineer and Principal Investigator.

TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION AND SUMMARY	1
EVAPORATION	1
EVAPORATION MATERIAL STUDY.	2
X-Ray Analysis	4
Film Properties.	4
Cell Properties.	7
COLLECTOR ELECTRODE	7
Electroforming	7
Nickel Grid Material	8
Other Grid Materials	10
SUBSTRATES.	10
PILOT LINE	10
CELL PACKAGE.	11
Plastics	11
Encapsulation.	11
Lead Attachment.	12
Other Improvements	12
EQUIVALENT CIRCUIT MODELS	14
WORK PLANNED FOR NEXT PERIOD.	18
REFERENCES	19
COST SECTION.	20

LIST OF TABLES

<u>TABLE</u>		<u>PAGE</u>
I	Quantitative Spectrographic Analysis of Materials	3
II	X-Ray Data For Thin Films	5
III	CdS Evaporated Film Properties.	6
IV	1" x 3" Cells Delivered for Thermal Cycling . . .	13

LIST OF FIGURES

<u>FIGURE</u>		<u>PAGE</u>
1.	Rear Wall Cell Fabricated By Etching Substrate .	9
2.	Actual and Calculated I-V Curves	15
3.	I-V Curves at Three Intensities for Estimation of Series Resistance	17

INTRODUCTION AND SUMMARY

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This report describes the work performed during the fifth period of a research and development contract on CdS thin film photovoltaic cells sponsored by the Lewis Research Laboratory of NASA with Dr. Andrew E. Potter acting as contract monitor.

During this period a study was initiated to compare films evaporated from different CdS materials. These films were compared for crystal size, orientation, resistivity, mobility and carrier concentration. Cells were also made with these films and the results are included in the study.

Some work is reported on attempts to electroform the collector mesh in situ.

The molybdenum substrate thickness has been reduced to one mil, but its use is limited by the condition of the material as supplied.

Preliminary work was accomplished in designing a new lamination process which would have a short heat and cool cycle, thereby insuring less damage to the transmission and other physical properties of the plastics.

Certain improvements in the cell package are discussed.

Equivalent circuit models are also reviewed.

The work planned for the next period is outlined.

AUTHOR

EVAPORATION

When the evaporated CdS film cell evolved from the CdS single crystal cell the original material used as an evaporant was single crystal material. Subsequently it was discovered that it was possible to use sintered polycrystalline material as an evaporant. Now, as described in the last report⁽¹⁾ raw powder has been found to be suitable as an evaporant. Powder supplied by several manufacturers has been tried, but only the G.E. material has been handled satisfactorily by the present tooling in the evaporators. With other materials there was considerable spattering on the films. This spattering has been found to be due to the grain size as is shown in the following comparison. The grain sizes as found by microscopy were:

G. E. Powder:

Range = less than 1 micron to 3 microns

Majority = 1.5 microns to 2 microns

Merk Powder:

Range = less than 1 micron to 50 microns

Majority = less than 1 micron to 1.5 microns

Sylvania Powder:

Range = less than 1 micron to 40 microns

Majority = less than 1 micron to 1.5 microns

Evidently the production process of CdS powder varies with each supplier. Some inquiries will be made to the various suppliers to determine what might be done to obtain a more uniform particle size.

In the meantime, there are two methods that can be used to handle evaporants containing many fines. First the filaments can be modified in an attempt to eliminate this spatter. Thicker quartz plugs might be sufficient. If not, the filament can be redesigned to incorporate the proven method of forcing the vapors to make enough 90° turns, so that all the fines drop out, and remain behind when the CdS vapors leave the filament.

A second method is to charge the filaments with pellets produced by pressing the powder. The results obtained from the use of pressed pellets indicate that this procedure is satisfactory. However, the pellet press that was available for this purpose added too many contaminants to the powder, and hence to the films. It was also indicated that the pressures used to form the pellets should not be very great, or the evaporation rates become very unpredictable. Pressed pellets should prove most convenient for a production process.

EVAPORATION MATERIAL STUDY

As stated above many types of starting materials can apparently be employed to produce good CdS film cells. A study was initiated to compare several starting materials, and the films and cells produced from them. The crystal orientation, grain size, resistivity, mobility and carrier concentration of the films were examined. The electrical characteristics of the cells made from these films were also studied.

The materials selected for this comparison were General Electric powder, sintered General Electric powder, Sylvania powder, Merk powder, Eagle-Picher powder, and single crystal material grown from General Electric powder.

Table I shows the spectrographic analysis for certain impurities in these materials.

Except for the large amount of calcium in the Merk powder, it is evident that there are no great significant differences in impurities in the various materials. The particular batch of General Electric powder included in these tests actually looked best. Both the sintered material and the single crystal material were made using the G.E. powder as a starting material. Certainly because of the complete dissociation that occurs in the evaporation process, and the vapor pressures present some further purification will occur during film desposition.

TABLE I

QUANTITATIVE SPECTROGRAPHIC ANALYSIS OF MATERIALS

	G.E. POWDER (ppm.)	SYLVANIA POWDER (ppm.)	MERK POWDER (ppm.)	EAGLE PITCHER POWDER (ppm.)	SINTERED G.E. POWDER (ppm.)	SINGLE CRYSTAL FROM G.E. POWDER (ppm.)
Aluminum	<2.0	2.3	6.0	3.0	<2.0	4.3
Calcium	1.7	1.5	>50.0	2.0	2.1	2.2
Copper	<1.0	2.4	1.1	2.0	<1.0	<1.0
Indium	<1.0	1.2	<1.0	2.0	1.1	2.6
Iron	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Magnesium	<1.0	1.2	2.5	2.0	<1.0	<1.0
Manganese	-	-	-	-	-	-
Nickel	-	-	-	-	-	-
Silicon	<2.0	6.2	3.5	4.0	2.0	10.0
Thallium	-	-	-	-	-	-

X-Ray Analysis

Thin films of the materials were deposited by use of the standard evaporator. The geometry of the vapor source, the substrate, and their respective heaters was similar to that previously reported.² Efforts were made to keep evaporating techniques constant. The purpose of the experiments was to determine what changes in film structure, if any, could be attributed to the CdS source material. If noticeable effects are absent, several forms of CdS are suitable for evaporating films. A priori CdS should evaporate and deposit in a manner which is independent of preparation. However, differences in impurity content, particle size and other chemical or physical properties may effect changes in the deposited films.

Films of the various CdS sources were evaporated on glass and molybdenum substrates which were in turn studied by x-ray techniques. For each evaporation onto molybdenum a glass substrate was included so that the film on the glass could be used for resistivity and hall measurements, since a non-conductive substrate is required. The films on molybdenum were used for cell fabrication. It was possible however to study films on both glass and molybdenum by x-ray.

After the evaporated CdS films were prepared, they were examined by x-ray procedures for lattice spacing changes, orientation, and relative crystallite size. The data have been assembled in Table II. It may be noticed that the d spacings of the (002) planes are constant at $3.359 \pm 0.01 \text{ \AA}$. The (002) planes are nearly parallel to the substrate and small differences in spacings may be caused by film thicknesses, strain, measurement error, and defect content. No specific data can be correlated with the source alone. The peak intensity of (002) is measured in a number of planes, or crystallites oriented parallel to the substrate. Many variables can change this orientation. The General Electric sintered power evaporated on glass substrates appears to give the best orientation. However, this could be fortuitous. It is known that biaxial orientation occurs in CdS films and more complete pole figures are needed to confirm results. The width at half maximum for (002) may be taken as an indication of crystallite size in a direction perpendicular to the substrate. Larger widths correspond to smaller crystallite sizes. Here again the range of observed widths is quite scattered. Definite correlations are difficult to form.

Likewise the widths are influenced by strain and other defects which are always present in the films. In conclusion the limited data given here show no outstanding differences which may be attributed to the original source of the CdS.

Film Properties

The resistivity, mobility, and carrier concentration were also determined for the films made from the various source materials. Table III lists the results.

These measurements indicated that the films made from G.E. powder display a resistivity of about an order of magnitude higher than those made from sintered material. Because of the higher resistivity, the thinness of the films,

TABLE II

X-RAY DATA FOR THIN FILMS

COMMERCIAL SOURCE	SAMPLE NO.	SUBSTRATE	d in Å ^o of (002)	PEAK INTENSITY OF (002) cp	WIDTH AT HALF MAXIMUM FOR (002) (2°)
General Electric Sintered	X580	Pyrex	3.359	49,500	.191
General Electric Sintered	51	Glass	3.364	75,000	.238
General Electric Sintered	57	Glass	3.359	100,000	.238
General Electric Sintered	74	Glass	3.368	68,000	.172
General Electric Sintered	73	Glass	3.365	65,000	.203
General Electric Sintered	47	Glass	3.362	5,760	.215
General Electric Powdered	47	Mo	3.354	40,000	.252
Sylvania Powdered	54	Glass	3.362	4,000	.195
Merck Powdered	53	Mo	3.358	22,600	.203
Merck Powdered	53	Glass	3.359	35,000	.211
Eagel-Pitcher Powdered	X588	Pyrex	3.361	4,800	.164
Harshaw Single Crystal	X586	Pyrex	3.361	871	.218

TABLE III

CdS EVAPORATED FILM PROPERTIES

MATERIAL	SAMPLE NO.	THICKNESS MILS	RESISTIVITY OHM CM	MOBILITY CM ² /V. SEC	CARRIERS CM ⁻³
GE Sinter	57	1.1	28	0.55	4.8×10^{17}
GE Sinter	51	1.8	--	--	--
GE Sinter	74	1.5	27	0.4	6×10^{17}
GE Sinter	X579 X580 X581	2.0 2.0 2.0	16	1.9	2.5×10^{17}
GE Powder	47	1.7	560	--	--
GE Powder	73	0.7	--	--	--
GE Powder	77	1.6	270	--	--
GE Powder	80	1.0	1200	--	--
GE Powder	82	1.5	1400	--	--
Sylvania Powder	49	1.2	0.6	1.5	8.5×10^{18}
Sylvania Powder	54	0.5	--	--	--
Eagle Pitcher Powder	X588 X589 X590	1.3 1.3 1.3	240	3.9	7.9×10^{15}
Harshaw Single Crystal	X585 X586 X587	1.5 1.5 1.5	4.6	3.7	4.3×10^{17}

and the available equipment, no measurements of the mobility or carrier concentration for the G.E. powder films was obtained. The Sylvania powder films showed a very low resistivity, and a slightly high carrier concentration. A much lower carrier concentration was measured in the Eagle-Pitcher films which displayed a high mobility. More data will have to be obtained to complete the picture.

Cell Properties

The films from the various materials were processed into cells in order to check the electrical properties of the finished cells. Because of the spattering on the films made from Sylvania and Merk powder, it was not possible to fabricate cells from these materials. In general the efficiencies ranged from 1.5% to 3.0% in each group except those made from single crystal. These averaged only 1% to 2%. In the past many very good cells have been made from single crystal material.

No significant differences were noted in open circuit voltages, or short circuit currents in any one group of cells.

One property that did vary was the shunt resistance. To evaluate this property the value of shunt resistance obtained from the I-V Curves was multiplied by the cell area because the cell areas varied from 12 cm² to 210 cm². This normalized value of shunt resistance ranged from 100 ohm cm² to 31×10^3 ohm cm². It is felt that this great variation is due to the film structure, and in particular to the partial shorting paths such as pin holes, grain boundaries, etc.

The series resistance is of special interest since a decrease of this property would mean an immediate increase in cell efficiency. In the past there appeared to be some indications that series resistance might be correlated to the bulk resistivity of the film.³ However after the values were adjusted by using the cell areas to obtain a common figure, no correlation was evident. The series resistance varied from 6 to 25 ohm cm². The film resistivities ranged from 0.6 ohm cm to 14×10^3 ohm cm. If much of the series resistance of the cell is due to the bulk resistivity of the film, it will be very hard to separate it from the total series resistance.

COLLECTOR ELECTRODE

The collector electrode that is presently used is a gold electro-formed mesh. This mesh is satisfactory in most respects, but is expensive and not as firmly attached to the barrier as might be desired. In order to overcome these problems, several approaches have been used. The most attractive procedure would be to electroform the mesh in place, on the barrier. This could be economical, and yield a collector firmly attached to the surface. An immediate answer to cost reduction is the utilization of other metals to replace the gold. Metals such as copper and nickel are available at about one-third the cost of the gold.

Electroforming

Some experiments have been carried out in forming a conducting metallic

grid on the barrier surface. The most successful method for forming the grid has been electroplating through a photo-resist mask. Selective etching of an evaporated or plated metallic film has also been tried.

The cells that had collector grids made by electroplating copper through a mask on the barrier surface suffer from a rather low open circuit voltage, although short circuit current is high. This seems to indicate efficient current collection by the copper grid. The reason for the low V_{oc} is not understood, but is probably associated with an attack of the barrier layer by the plating solution. It may be possible to reform the barrier layer under the copper grid lines by an appropriate heat treatment. There is also the possibility of forming the collector first and then the barrier. The barrier formation process would not be electroplating, but rather by direct chemical deposition.⁴ So far experiments in this direction have proven negative.

Twenty-five lines per inch grids with 90% transmission can be formed by photo-resist techniques, and 70% transmission can be achieved with 70 lines per inch by the state of the art in this laboratory. It is expected that the transmission can be improved in the future.

It is planned to try gold grids plated from a nearly neutral solution in the hope that, in this way, the open circuit voltage can be raised to the levels obtained with conventional laminated grids. Attempts will also be made to plate grids on titanium or stainless steel substrates, and then strip them off intact for use in the conventional gridding process. This would not only be economical but would provide a much cleaner surface on the mesh. The mesh presently used is formed months before it is used and accumulates much contamination on the surface.

In an effort to avoid attacking the thin barrier with the plating solution, an attempt was made to fabricate a rear wall cell by painting the barrier surface with an opaque silver paste, and selectively etching out a grid on the other side, in the cell's molybdenum substrate. This technique shows some promise, but it is hampered by the lack of an etchant which will remove molybdenum and not remove the CdS below. This method does have the advantage of etching from the n-type CdS side of the cell. This material is about one-and-one-half mils thick, so that if the etching solution removes only part of the CdS it probably will not effect the cell operation. Figure I is a picture of an operating rear wall cell that was fabricated in this manner. It does present a handling problem since the CdS film is practically unsupported when most of the molybdenum is etched away.

Nickel Grid Material

Various test cells were constructed using a 70 lpi Ni grid and an Au grid as a standard. In all cases the gold grid proved superior to the nickel grid immediately following lamination. However, after several months on one particular cell with a Ni grid, the efficiency increased from 1.96% to 2.16% and the gold standard grid remained constant at 2.14%. On the average the gold yields a higher efficiency with the present techniques used in cell fabrication. Annealed Ni grids will be tried along with varying the lamination pressure to determine what effects, if any, these factors have on the Ni grid

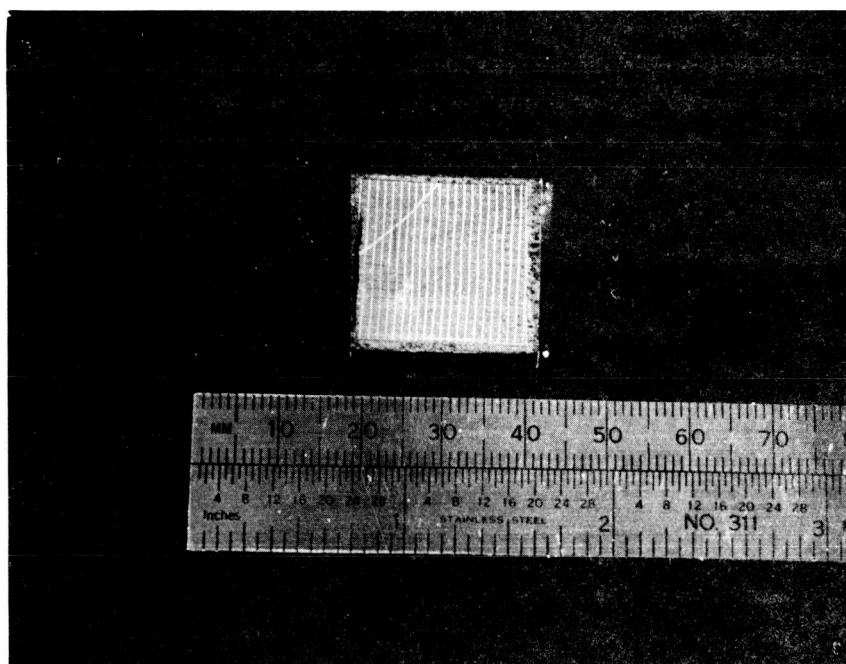


Figure 1
Rear Wall Cell Fabricated By
Etching Substrate

efficiency.

Other Grid Materials

Copper also seems to be a grid material which shows promise over an extended period of time. The annealing pressure and cleaning which are to be tried on the Ni grid could also be applied to the Cu as well.

Cleaning solution called Nutra-Clean has been used successfully on some gold grid material. Further cleaning methods will be investigated and the cleaning of the Ni and Cu will also be tried.

Expanded mesh of aluminum, silver, and nickel grids were obtained and will be tested against a standard gold grid.

SUBSTRATES

One way to reduce the weight and increase the watts per pound ratio is to use a thinner or less dense substrate. One mil molybdenum has been substituted for the two mil molybdenum in the past, but only for small area cells. In this reporting period work was done to develop a facility for handling one mil molybdenum as substrate material for 6" x 6" films. Several 6" x 6" cells were made using one mil molybdenum. However, great care must be taken to avoid any kinks or folds in the foil. This is especially true during the etching. This is so difficult that, at present, the material has to be taped on a plastic board and then etched on the side that is to be used. This minimizes the wrinkling and denting of the thin substrate. Perhaps some plastic holder employing suction will be constructed.

However, the biggest problem in preparing one mil molybdenum for large area substrates is the condition of the material as supplied, because much of the material is already full of dents and folds. The suppliers are being consulted as to their limitations.

Not much work was done during this period on other substrate materials. However, some two mil zirconium and titanium has just been received. More work is also scheduled for invar and other attractive alloys. The work will concentrate on the surface preparation of these substrates.

PILOT LINE

In order to supply cells for experiments and to provide a base line for comparison, a standard pilot line is continually operated. This line has proven its worth time and time again in providing answers to both improvements and in solving temporary difficulties.

About three-hundred-fifty cells were produced on the pilot line during this period. The average efficiency was 2.1% for 1" x 3" cells, and 2.4% for 3" x 3" cells. The highest efficiency was 4.0%. The average efficiency is rather low, but it can be attributed to equipment changes. For instance, one of the major changes, and resulting temporary drop in efficiency during the period was the retooling of an evaporator to handle 6" x 6" substrates enabling this piece of equipment to put out four times its previous yield.

Naturally in establishing this change several poor films were made until all the necessary adjustments were completed.

The conversion to 6" x 6" areas is a direct result of this contract under which the process was developed. These large areas are handled as conveniently as smaller areas.

CELL PACKAGE

At present the complete cell package comprises the CdS film and barrier layer on a molybdenum substrate, a mesh collector, negative and positive leads, and the plastic envelope. In this section the substrate, film, barrier, and mesh are not considered. Interest is directed to the plastic, methods of encapsulation, and the lead attachment.

Plastics

Using samples supplied by Harshaw, the NASA, Lewis Laboratory performed some preliminary UV tests on the films. Using this information, the data supplied by the manufacturers, and the experiences gained in this laboratory, the most favorable plastics for cell encapsulants were selected. The properties looked for in the plastics were UV, temperature, and radiation resistance. The plastic must also possess sufficient tensile properties. The three plastics that look best for space use are duPont's H-film, duPont's Tedlar, and Mylar. H-film is a polyimide, while Tedlar is a polyvinyl fluoride.

Lamination of one mil H-film to itself was not successful, and an adhesive layer of nylon had to be used. No adhesive is needed for the Tedlar since it has a special heat sealable surface.

These three plastics will be compared in further tests by NASA. These tests include radiation resistance, U.V. resistance, thermal properties, moisture permeability, and other physical properties such as tensile strength and elastic modulus.

Encapsulation

Because of the long heating and cooling cycle used in the present lamination process, and the difficulty this causes in handling certain plastics, a new technique is being sought. The present method is too slow. It is also true that the optical and physical qualities of the plastics are less effected by a rapid heat and cool cycle than by the present much longer cycle.

An attractive method would be impulse lamination. Several samples were sent to each of four companies for sealing experiments. Only those sent to General Electric, Miniature Lamp Division, were successfully sealed. Mylar-nylon and Kel-F plastics were laminated with results that appear equal to those presently obtained by the long cycle method. General Electric suggested that they seal our cells on a sub-contract basis since their process is proprietary.

Some work was initiated here on an impulse type sealer. The most favorable

results have been obtained on what might be termed a "resistance heating" type system. Large amounts of electrical power are necessary for short periods of time. However after several tests, it is felt that specifications for a piece of equipment including the proper power supply can now be drawn.

Another type of sealer that has been investigated is the heated roller type. This seals the plastics well but tends to trap vapors at the edges of the cell. There are ways that a new package could be developed employing this heated roller technique. It might also be employed in preassembling the package e.g. putting the mesh collector on the barrier.

Lead Attachment

One weak point in the cell package is the negative and positive lead attachment. Until now this has been only a pressure contact established during the lamination process.

To alleviate the problem of the pressure contacts (silver to the molybdenum, and silver to the gold mesh) separating, other precautions shall be taken.

In order to insure a good contact to the molybdenum substrate, a tab will be extended from one edge. This molybdenum tab will have to be treated by plating or some other process which will allow it to be tinned for soldering. An alternate method is to spot weld a solderable metal tab to the substrate.

There are two methods of attaching the positive silver lead to the mesh. One is thermal-compression bonding. The other is to have the lead tinned before lamination, then under the conditions of temperature and pressure of lamination, a solder joint is formed between the mesh and lead. From preliminary tests it appears that certain fluxes must be avoided as they damage the barrier.

All other connections, e.g. terminals on the end of the leads, will be spot welded.

These improvements should insure a cell package that will not lose electrical contact under extreme temperature conditions.

Other Improvements

During this reporting period, 12 each 1" x 3" cells were supplied to the contract monitor for thermal cycling tests. These cells are shown in Table VI.

Some cells have been tested at very high temperatures. Other cells are still to be tested. However from the results of the tests at extreme temperatures, it was evident that some changes should be made in the cell package. One problem area that showed up was the cutting of the plastic by the edges of the substrate during temperature cycling. This is due to the expanding and contracting metal working against the plastic at the edge of the metal substrate. The plastic is thinned in this area during the lamination process.

TABLE IV

1" x 3" CELLS DELIVERED* FOR THERMAL CYCLING

CELL NO.	SAMPLE NO.	ENCAPSULANT	OCV VOLTS	SCI Ma.	AREA Cm ²	EFF. %
712MN	X511	Mylar Nylon	0.5	112	13	2.64
711MN	X508	Mylar Nylon	0.48	130	13	2.75
710MN	X560	Mylar Nylon	0.49	124	13	3.17
709MN	X551	Mylar Nylon	0.49	120	13	2.72
713MN	X507	Mylar Nylon	0.44	119	13	2.19
714MN	S667	Mylar Nylon	0.48	128	13	3.12
705S	X563	Scotch Pak	0.48	78	13	1.88
716S	W890	Scotch Pak	0.47	120	13	2.63
704S	X565	Scotch Pak	0.46	76	13	1.75
702S	X558	Scotch Pak	0.45	100	13	2.16
706S	X559	Scotch Pak	0.45	72	13	1.81
703S	X566	Scotch Pak	0.46	88	13	2.0

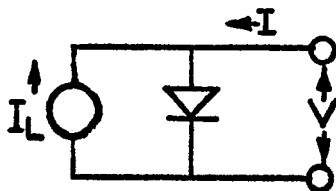
*These cells are to replace 1 each 6" x 6" array to be delivered before the end of the contract.

To prevent any cutting of the plastic by the thin metal substrate, the corners of the substrate will be rounded and the edges sanded. There will also be a plastic picture frame of reinforcement to eliminate the thin area in the plastic that the edges of the substrate work against when subjected to repeated expansion and contraction during temperature changes.

Still another improvement incorporated in the present package is the new black backing. The purpose of the black is to improve the emissivity of the package to about 0.9. Previously this black tended to chip off, now it is bonded to the plastic by heat.

EQUIVALENT CIRCUIT MODELS

It is of continuing interest to consider various equivalent circuit models for a solar cell. One model consists of a current generator shunted by a diode:



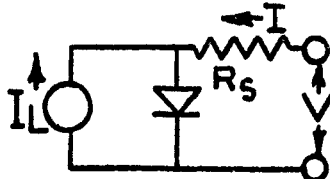
The output (I_L) of the current generator is a function (usually assumed linear) of the intensity of the light falling on the cell. The diode has an exponential characteristic, (saturation current, I_0). As a circuit element, the functional relationship of current (I) and voltage (V) of the model is given by:

$$I = I_0 (\exp (q V / A k T) - 1) - I_L$$

where q = the charge of the electron, k = Boltzmann's constant, T = the absolute temperature and A is a parameter given as equal to unity by the early diffusion theory of the silicon cell.

At this laboratory, E.R. Hill⁵ was able to "fit" curves of the above mathematical model to plots of experimental data obtained on cadmium sulfide solar cells, (refer to Fig. #2). The best fit of each curve was obtained using values from 3 to 4 for the parameter, A .

Another model adds a series resistance, R_s :



with the corresponding I-V relationship:

$$I = I_0 (\exp ((V - I R_s) q / A k T) - 1) - I_L$$

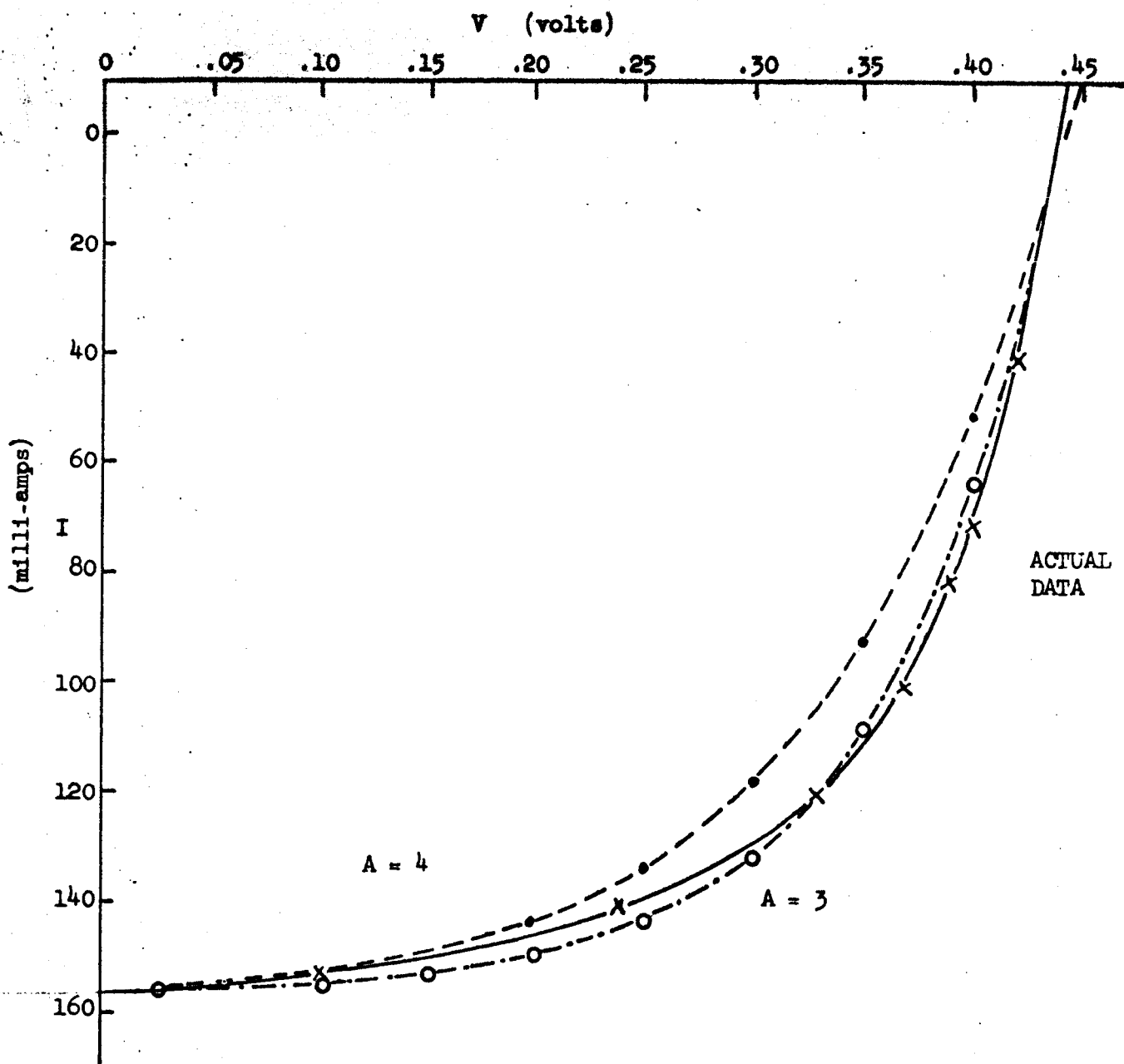
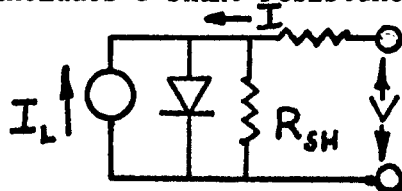


Figure 2
ACTUAL and CALCULATED I - V CURVES

When R_s has an appreciable effect on the I-V characteristic, its value can be estimated to be approximately equal to the reciprocal of the slope at the open circuit voltage intercept. Another way of estimating R_s involves taking experimental plots of the I-V characteristic of a cell at different light intensities.⁶ On the "knee" of each curve, a point is selected which has the same incremental difference in current from I_L , (refer to Fig. #3). A straight line is fitted to the points and the reciprocal of its slope is chosen as an estimate of R_s .

In the case shown in the Figure #3, R_s was estimated to be approximately 1 ohm. That value was also estimated from the slope at open circuit voltage on a scope trace of the I-V curve. The middle curve in Figure 3 was made under the standard light intensity and color of the routine laboratory cell tests. The effect of R_s was mathematically removed and the resulting data gave a value of A, approximately equal to 3.5.

A third model includes a shunt resistance R_{sh} :



Its I-V characteristic is conveniently expressed logarithmically:

$$\ln \left[\frac{I + I_L}{I_0} - \frac{V - IR_s}{I_0 R_{sh}} + 1 \right] = \left[q/kT \right] (V - IR_s)$$

Notice that there are five parameters: I_0 , I_L , R_s , R_{sh} , and A in this equation. It is possible to shift their relative values somewhat and yet keep the theoretical curve in a narrow channel about the experimental curve.

The above discussion suggests that different investigators may find different values for certain parameters depending upon how they have approached the problem.

Evaluation of the third model will proceed with the selection of five points, (V_1, I_1) , (V_2, I_2) , . . . (V_5, I_5) , from an experimental I-V curve. The I-V characteristic equation will be written for each of the points and will be solved for the five parameters. The method of successive approximations should yield values of the five parameters giving a curve which would pass close to the five selected points. The curve found in this way would represent the I-V characteristic of the cell to a degree limited partly by the accuracy with which the original points were chosen and partly by the inadequacies of the equivalent circuit model.

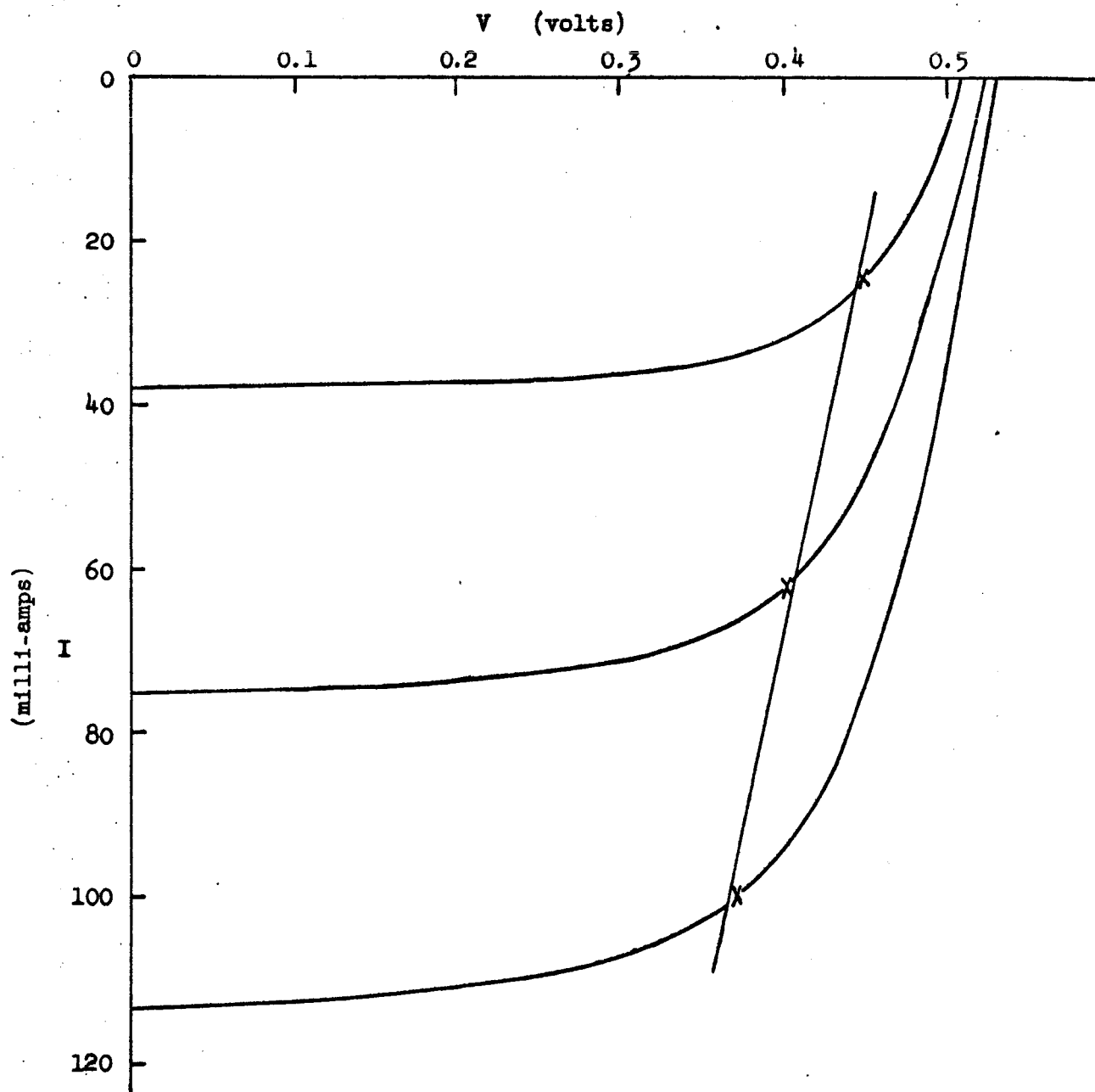


Figure 3

I - V CURVE at THREE INTENSITIES
for ESTIMATION of SERIES RESISTANCE

WORK PLANNED FOR THE NEXT PERIOD

Work will continue on handling one mil molybdenum as a large area substrate. Several other substrate materials will be tried with special emphasis on the surface preparation of these materials.

More measurements will be made on the films especially those from powder material. These will be correlated with the cell properties.

More work will be done on the resistance heating lamination technique. A working model will be designed.

Collector electrode work will be continued. Emphasis will be placed on finding a plating solution that will allow electroforming in situ without destroying the barrier.

During this period the rest of the cells stipulated in the contract shall be made and tested.

The production feasibility study will be completed at the end of this period.

REFERENCES

1. T. A. Griffin, J. C. Schaefer, and R. W. Olmsted, Fourth Quarterly Progress Report, Contract No. NAS 3-2493, Page 2.
2. T. A. Griffin and J. C. Schaefer, Third Quarterly Process Report, Contract No. NAS 3-2493, Page 2 & 3.
3. T. A. Griffin and J. C. Schaefer, Third Quarterly Progress Report, Contract No. NAS 3-2493, Page 8.
4. F. A. Shirland, G. A. Wolff, J. C. Schaefer, G. H. Dierssen, ASD - TDR - 62-69 Vol. II, Research on Solar Energy Conversion Employing Cadmium Sulfide, Page 8.
5. F. A. Shirland, G. A. Wolff, J. C. Schaefer, G. H. Dierssen, ASD - TDR - 62-69, Vol. II, Research on Solar Energy Conversion Employing Cadmium Sulfide, Page 25 ff.
6. P. A. Iles, the Present Status of Silicon Solar Cells, I.R.E. Transactions on Military Electronics Vol. MIL-6, Jan 1962, p 11 and J. Wolff and H. Rauschenback, Series Resistance Effects on Solar Cell Measurements, Advanced Energy Conversion, Vol. 3, No. 1 April-June 1963 p. 467.

COST SECTION

The following personnel have contributed to the work of this contract and charged time approximately as indicated during the period 26 July 1963 through 26 Nov 1963.

<u>Name</u>	<u>Duties</u>	<u>Hrs.</u>
J.C. Schaefer	Project Director	162½
T.A. Griffin	Principal Investigator-Supervisor	519
R.W. Olmsted	Physicist-Design and Testing	597½
W.W. Baldauf	Chemist-Array Encapsulation	308¼
D.H. Dickey	Physicist-Collector Fabrication	113½
R.W. Humrick	Physicist-Cell Fabrication	131
R.F. Belt	Physical Chemist-X-ray	63
J.D. Nixon	Physicist-Advisory	60
E.R. Hill	Physicist-Testing	15
E.L. Lind	Physicist-Advisory	6
Professional Hours		1975 3/4
Technician Hours		1355 1/4
Miscellaneous Analytical, Testing and Shop Labor		<u>24</u>
Total Labor Hours		3355
Total Labor Expenditures		\$12,771.14
At 104.97% Overhead		<u>\$13,405.87</u>
		\$26,177.01
Materials Costs		\$ 1,423.00
Attending Technical Meetings		<u>300.00</u>
		\$27,900.01